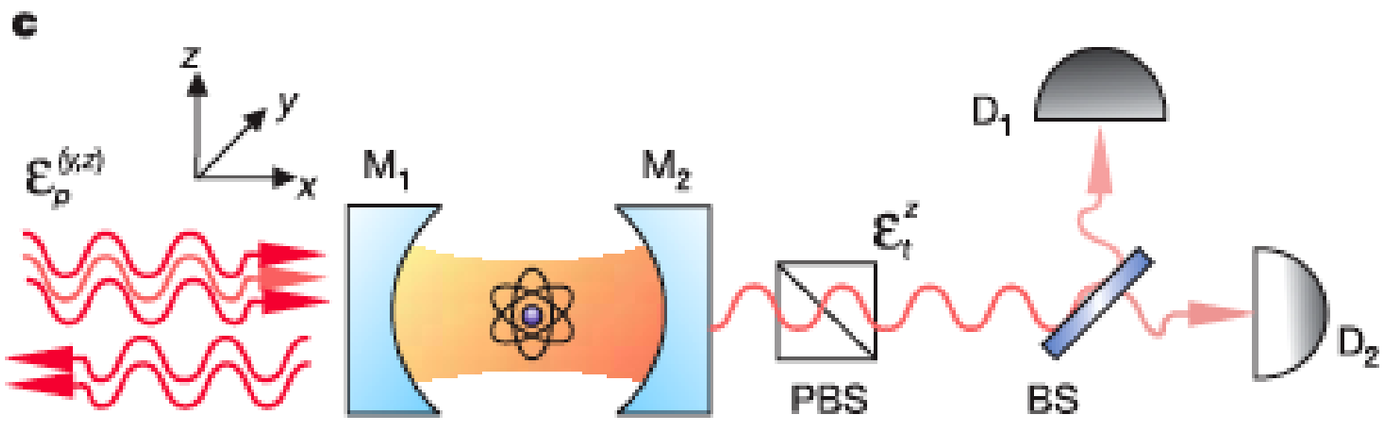
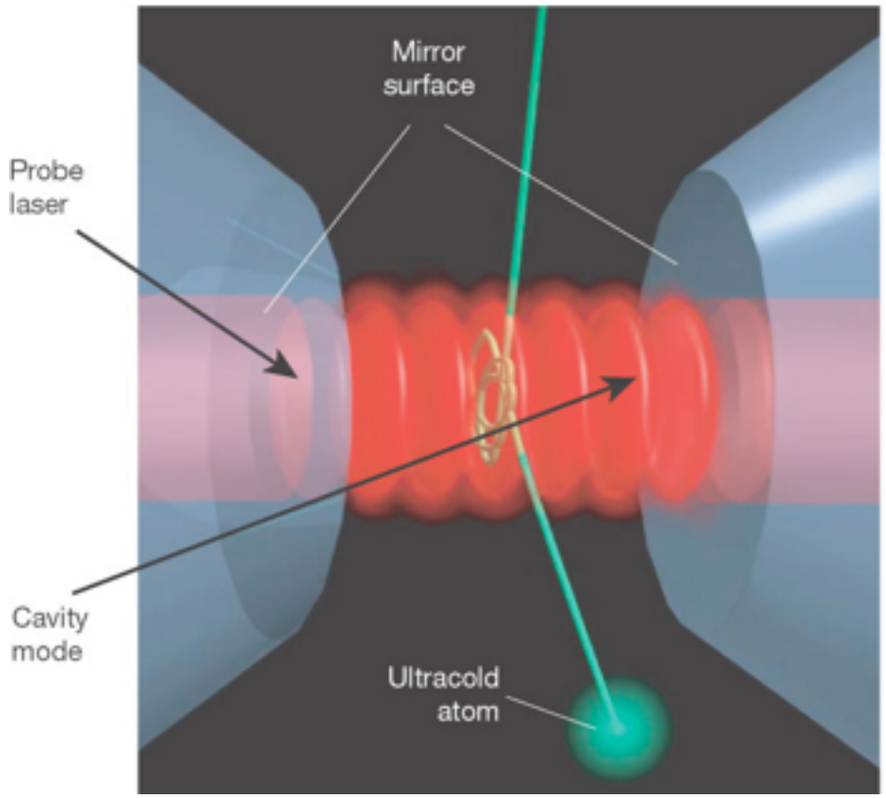
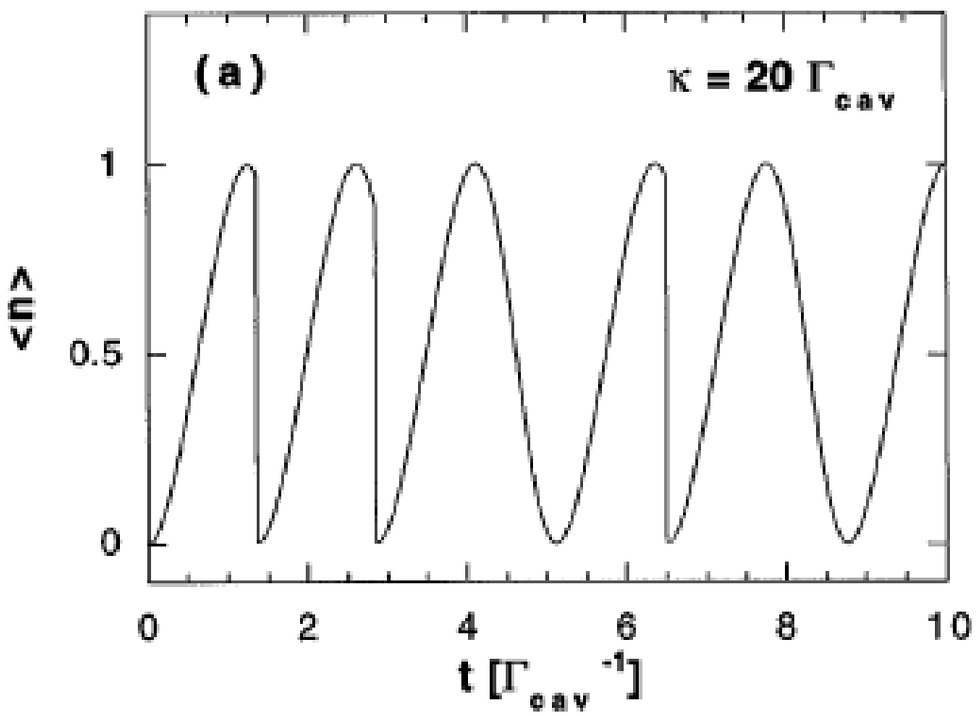
Photon Blockade







J.M. Raimond *et al*
Rev. Mod. Phys **73**, 565 (2001)

Atom-photon interaction leads to an effec. non-linear medium

A. Imamoglu *et al* 97, S. Rebic *et al* 99, J. Kim *et al* 99, K. Birnbaum *et al* 05

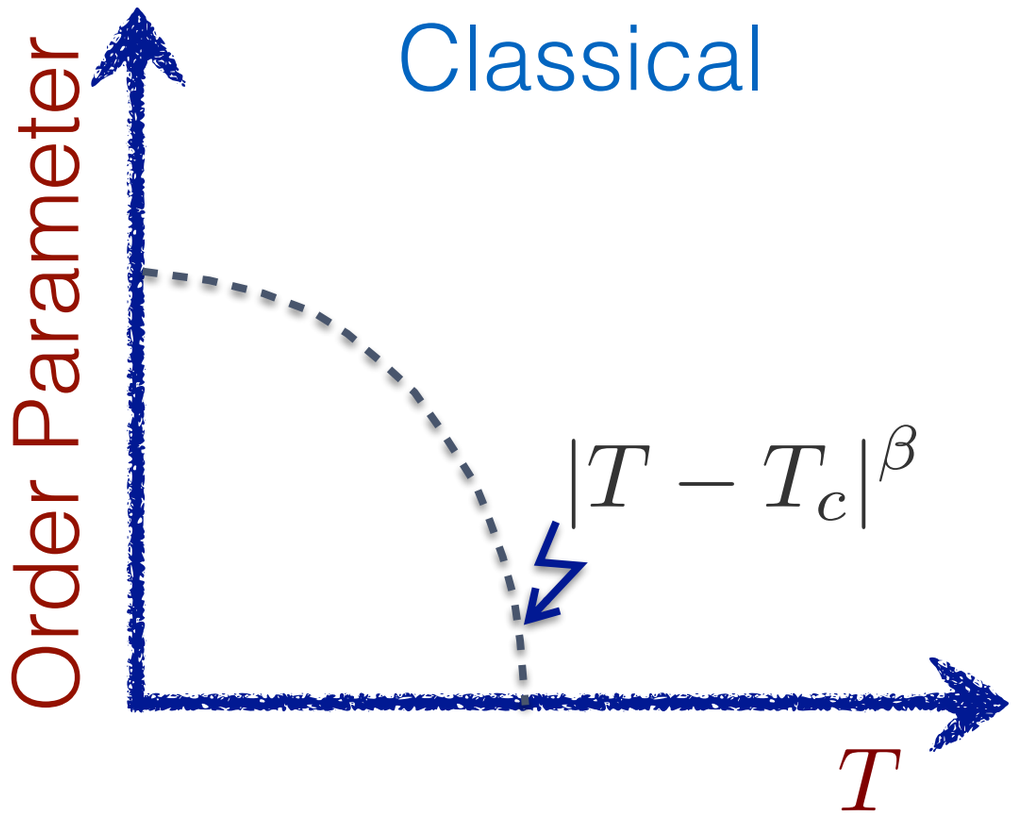
Many-Body Physics with photons

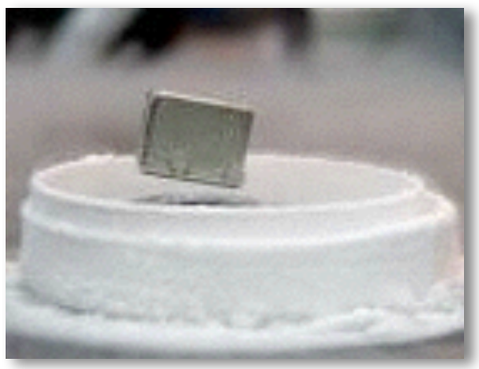
Rosario Fazio

J. Jin, D. Rossini, R. Fazio, M. Leib, and M. J. Hartmann, Phys. Rev. Lett. 110, 163605 (2013)
J. Jin, D. Rossini, M. Lieb, M.J. Hartmann, and R. Fazio, Phys. Rev. A 90, 023827 (2014)
M. Schiró, C. Joshi, M. Bordyuh, R. Fazio, J. Keeling, H. E. Türeci, arXiv:1503.04456

Phase Transitions

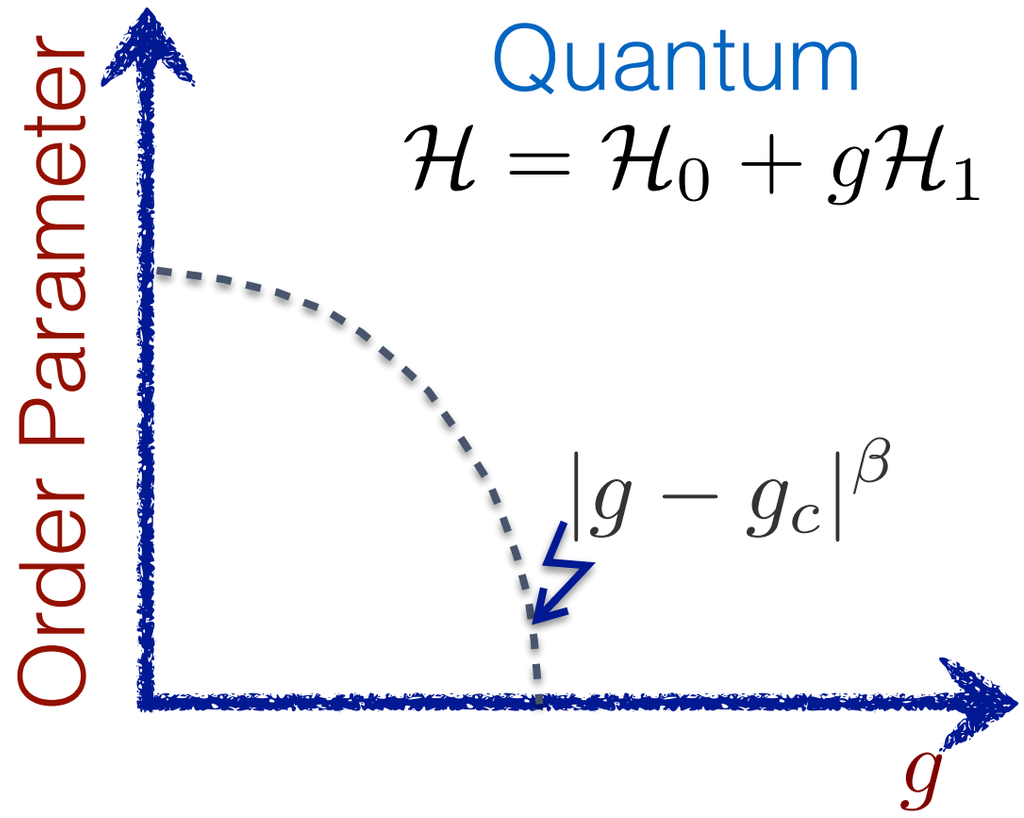
Classical





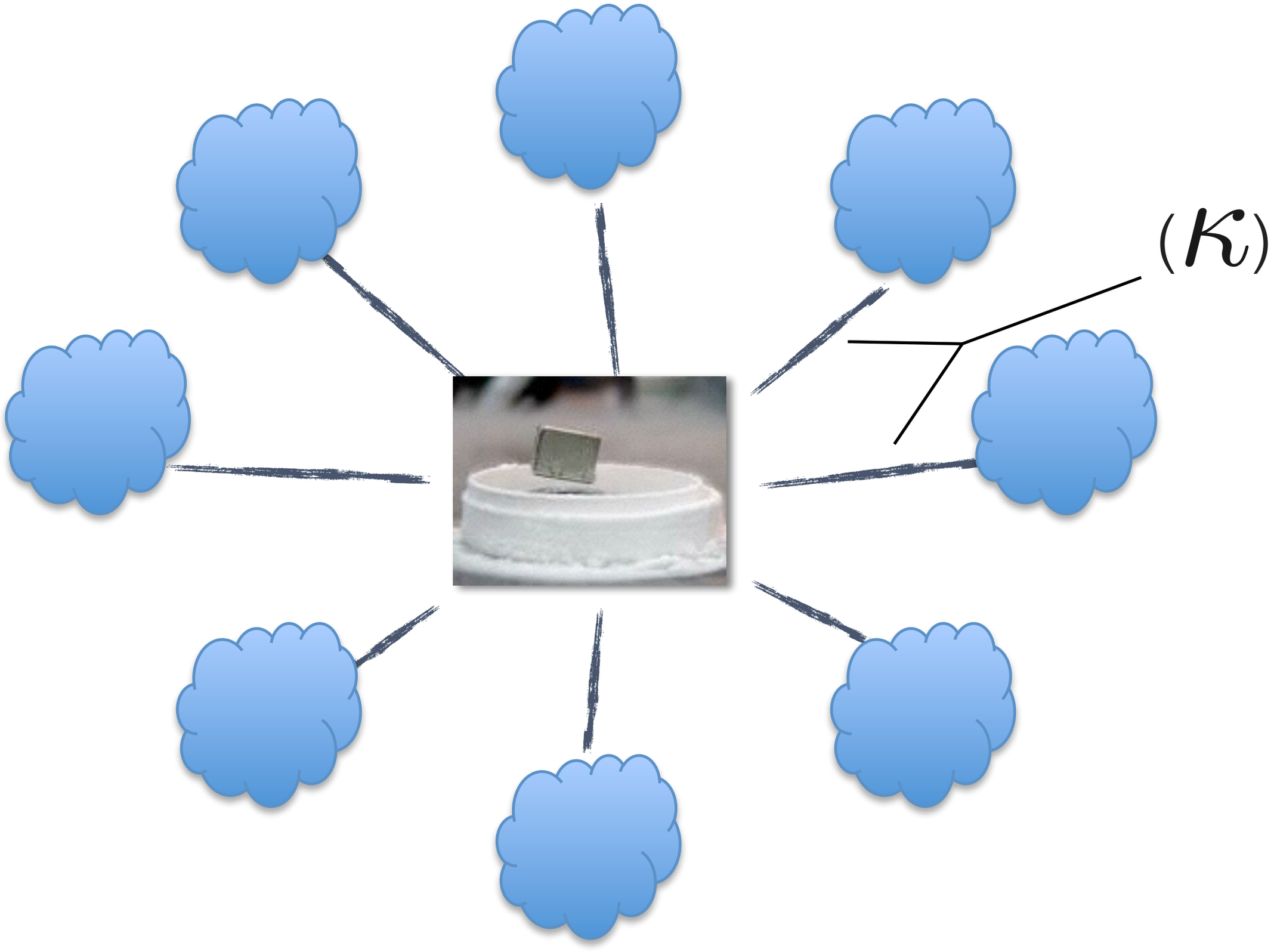
Quantum

$$\mathcal{H} = \mathcal{H}_0 + g\mathcal{H}_1$$



$$\xi \sim |g - g_c|^\beta$$

Coupling to the external world



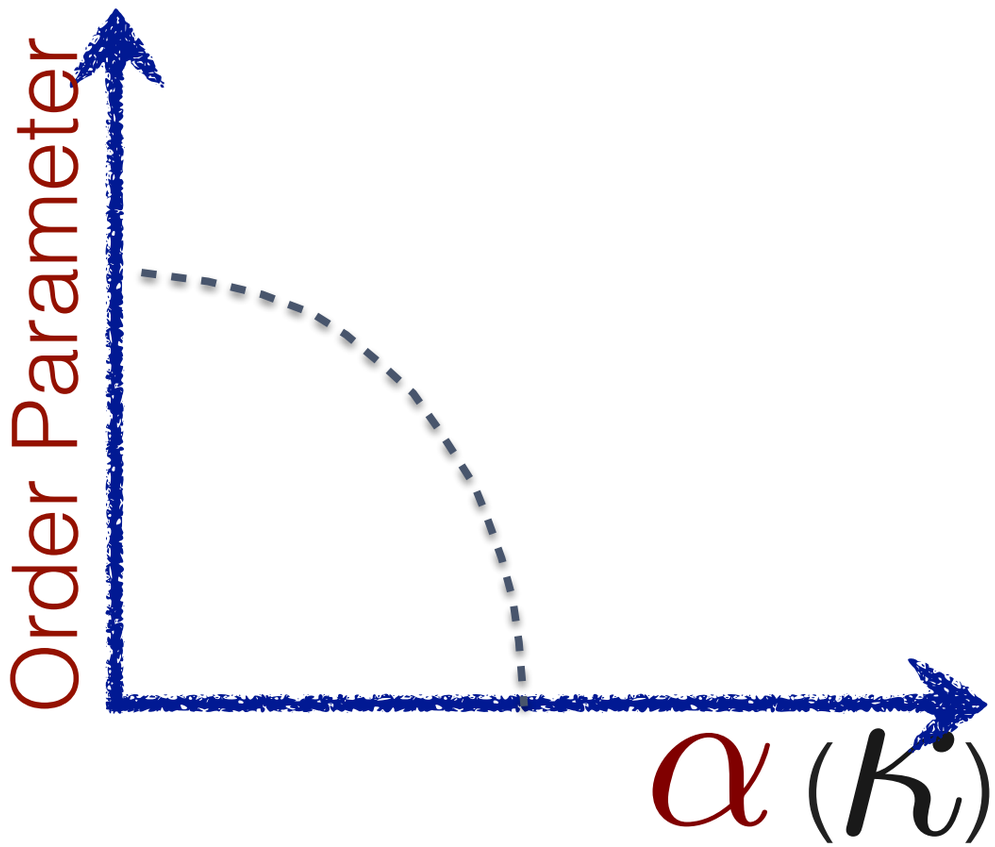
Coupling to the external world

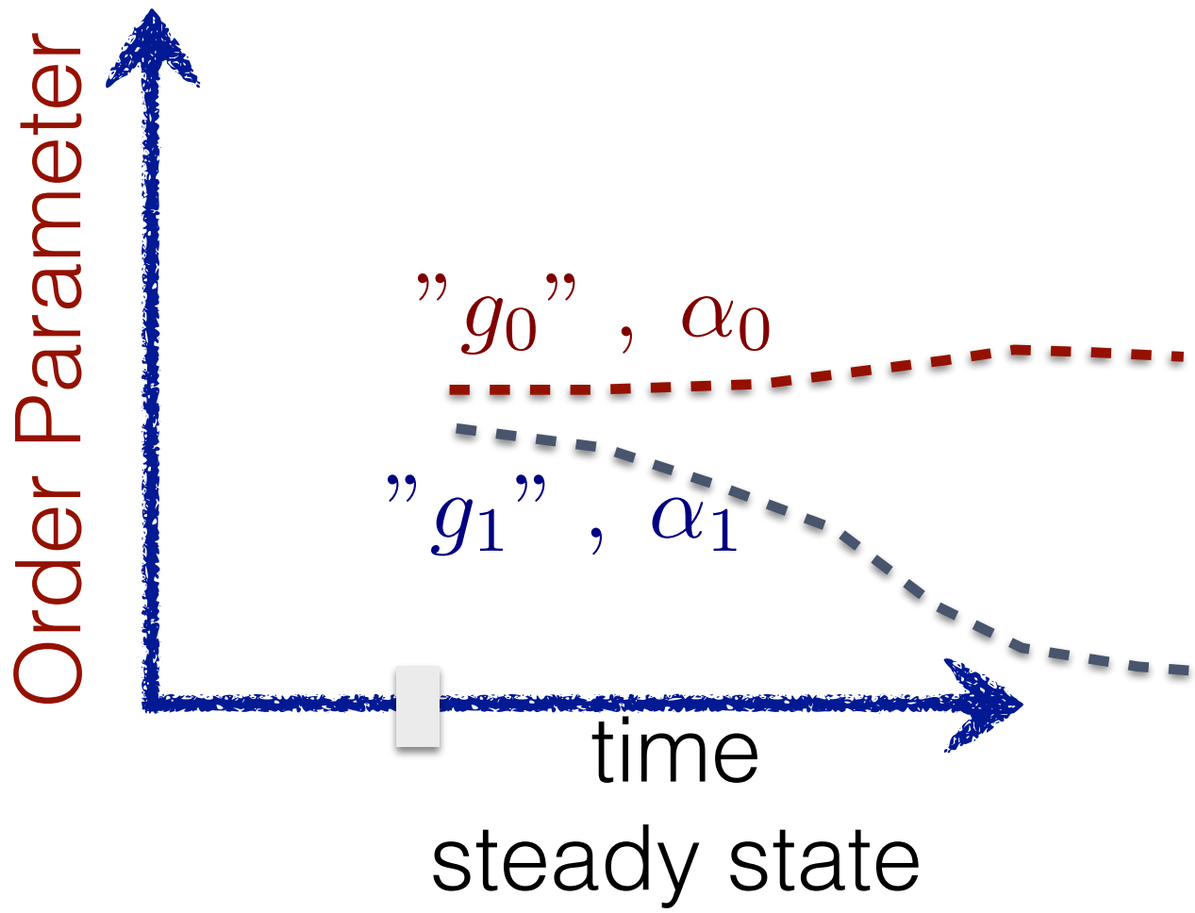
- Rich phase diagram
- Modified critical behavior
- Equilibrium vs non-equilibrium (symmetry-breaking,...)
- Nature of the coupling and properties of the bath (non-equilibrium environments)
- Engineered baths

Dissipative phase transitions

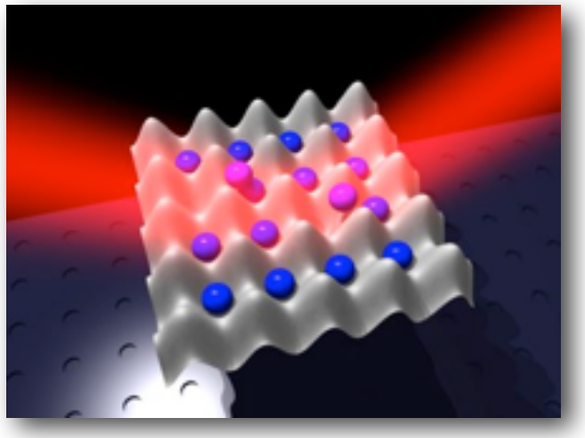
Order parameter - a property of the system

System + environment
(in equilibrium)

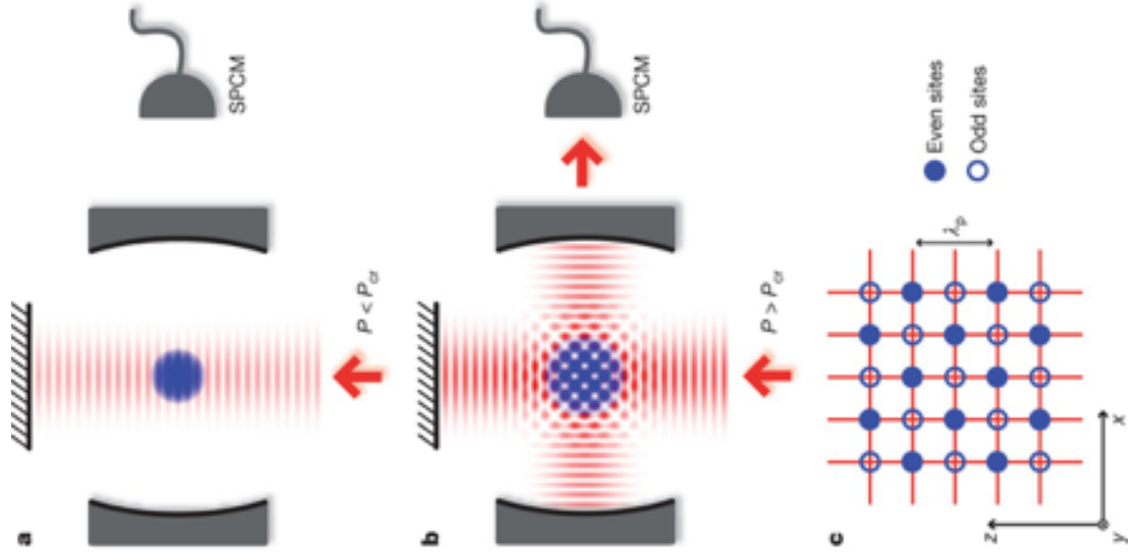




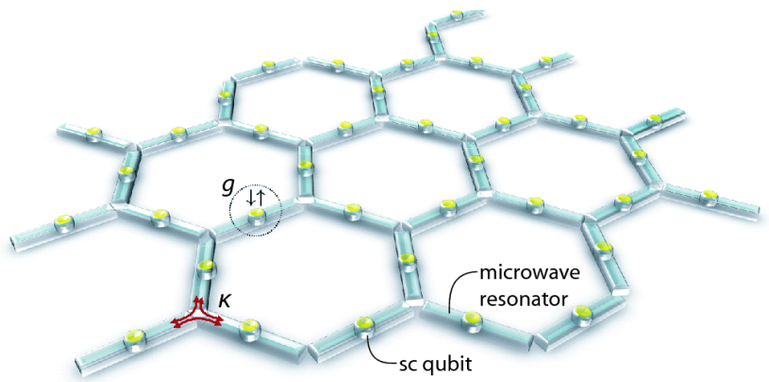
A variety of systems …



Optical lattices with engineered dissipation



BEC in cavities (Esslinger group)



Cavity arrays

. . .

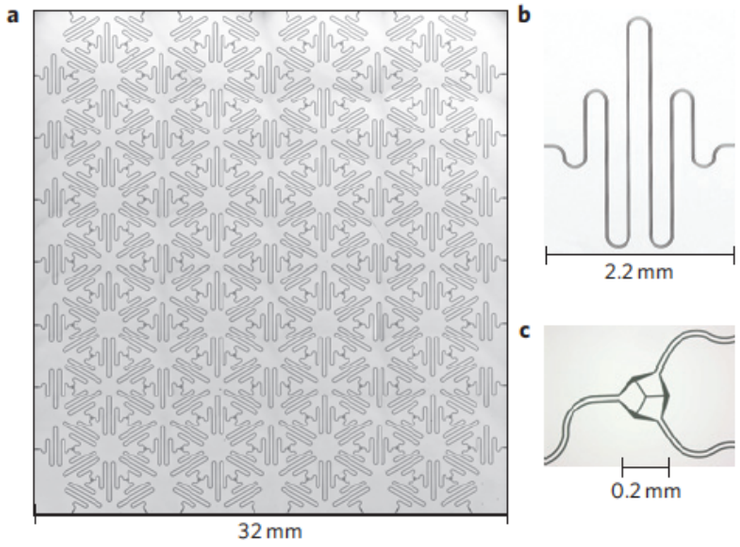
Master equation

$$\dot{\rho} = -i[\mathcal{H}, \rho] + \mathcal{L}[\rho]$$

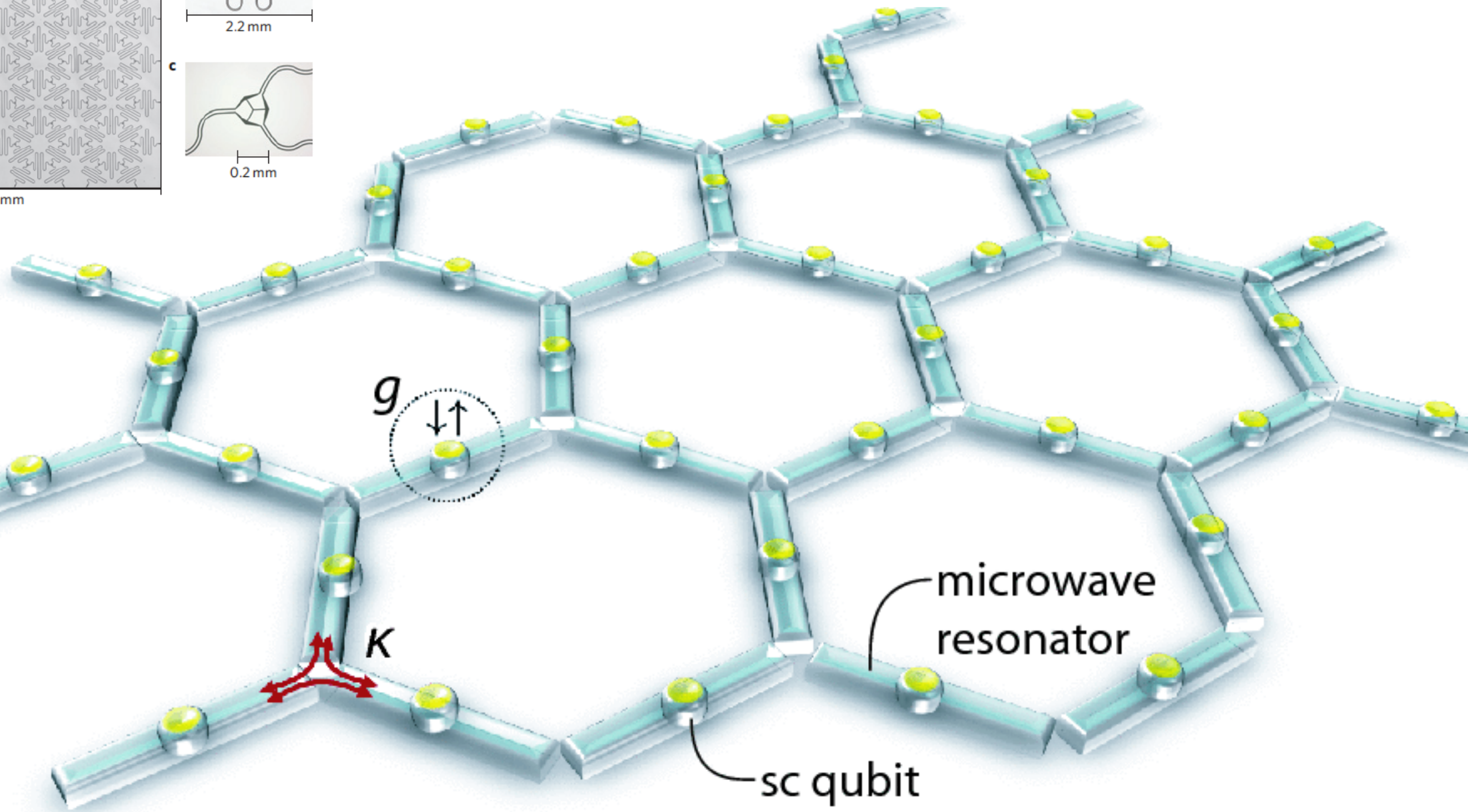
Competition of external driving and dissipation

Models with competition of strong local correlation and delocalisation

Coupled cavity arrays



Andrew Houck group



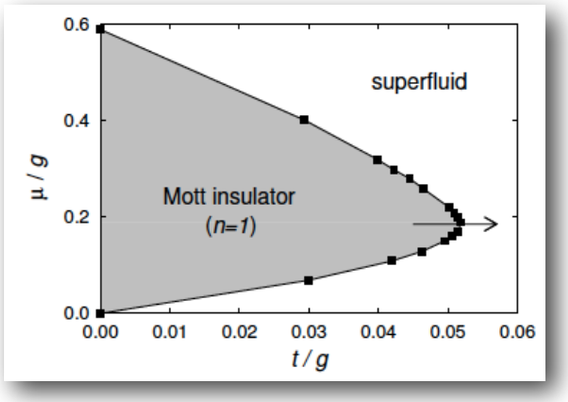
M. J. Hartmann, F.G. Brandao, and M. B. Plenio, Nat. Phys. 2, 849 (2006)
A.D. Greentree et al, Nat. Phys. 2, 856 (2006)
D.G. Angelakis, M.F. Santos, and S. Bose, Phys. Rev. A (RC) 76, 031805 (2007)

Coupled cavity arrays

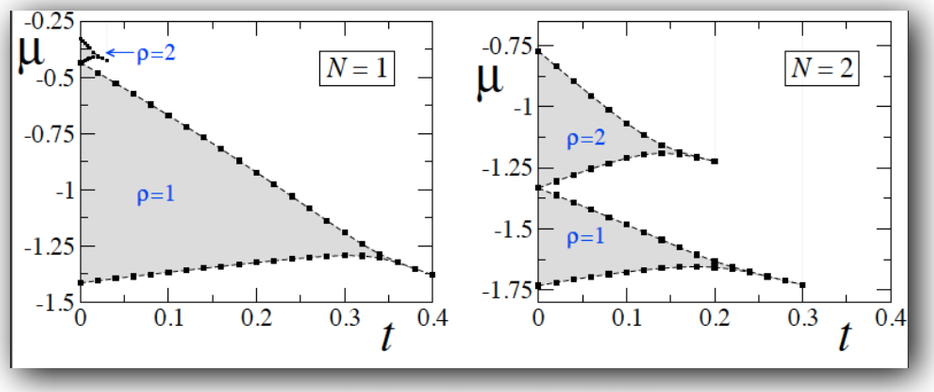
$$\mathcal{H} = \sum_i h_i - t \sum_{<ij>} (a_i^\dagger a_j + h.c.)$$

h_i "=" Jaynes-Cummings model

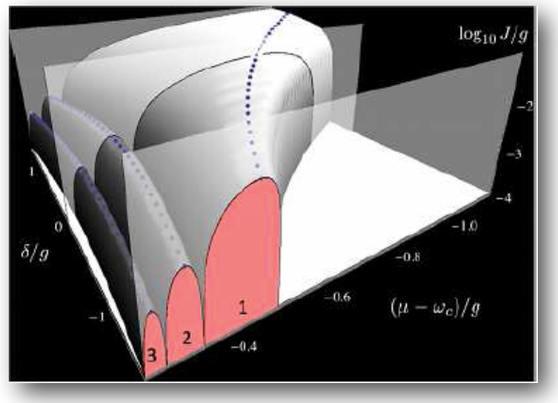
$$h_i = \epsilon \sigma_z + \omega a^\dagger a + \beta(a^\dagger \sigma_- + a \sigma_+)$$



Hohenadler, et al 2011

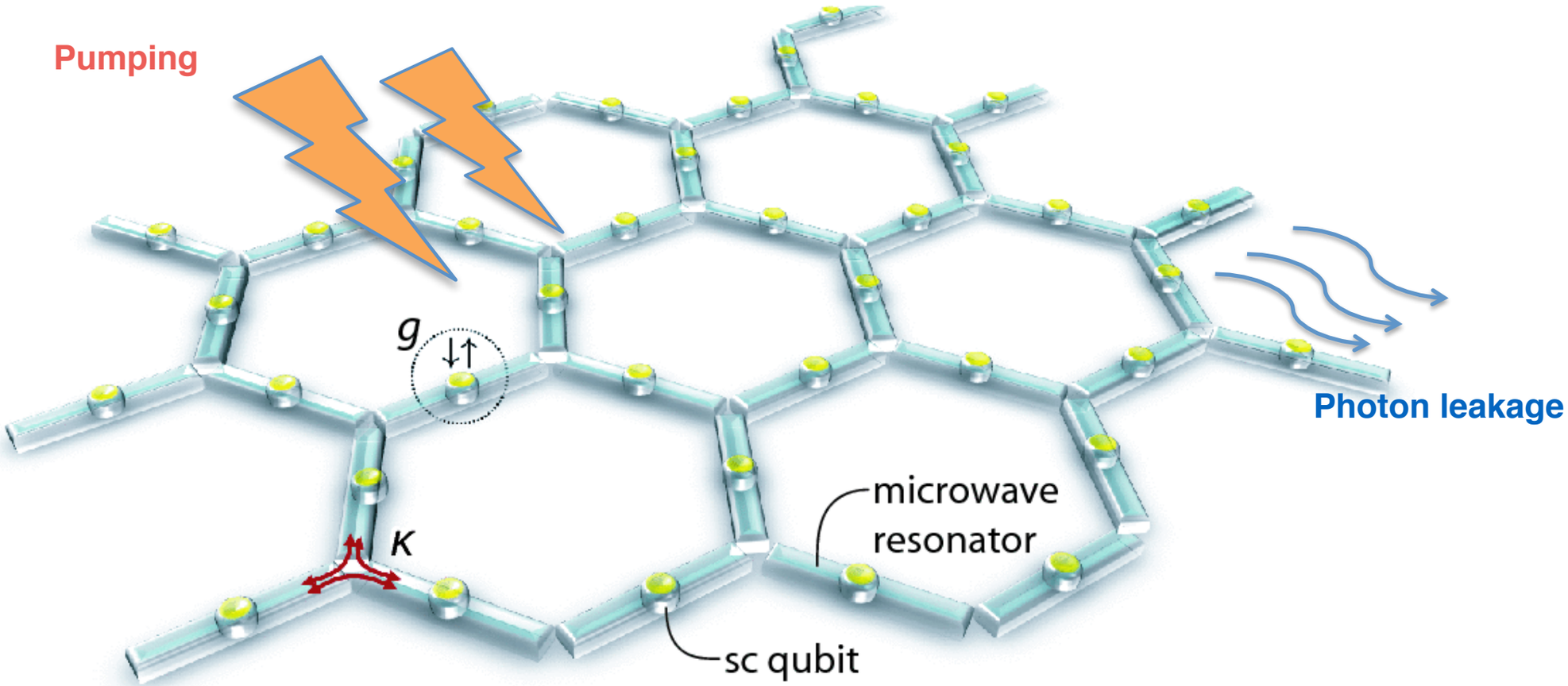


Rossini and Fazio 2007



Schmidt and Blatter 2009

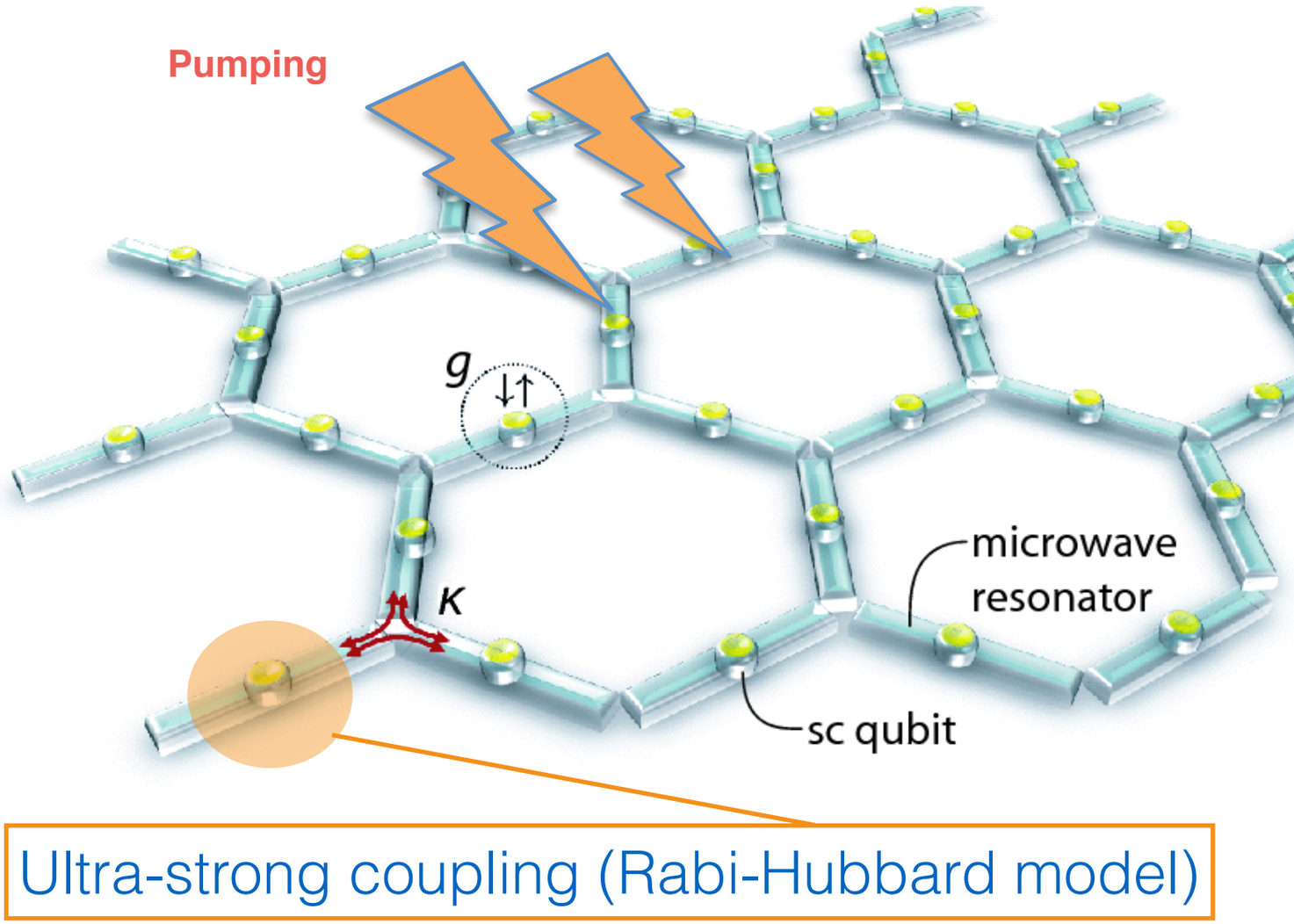
Coupled cavity arrays



$$\mathcal{L}[\rho] = \frac{\gamma}{2} \sum_i (2a_i \rho a_i^\dagger - \{n_i, \rho\})$$

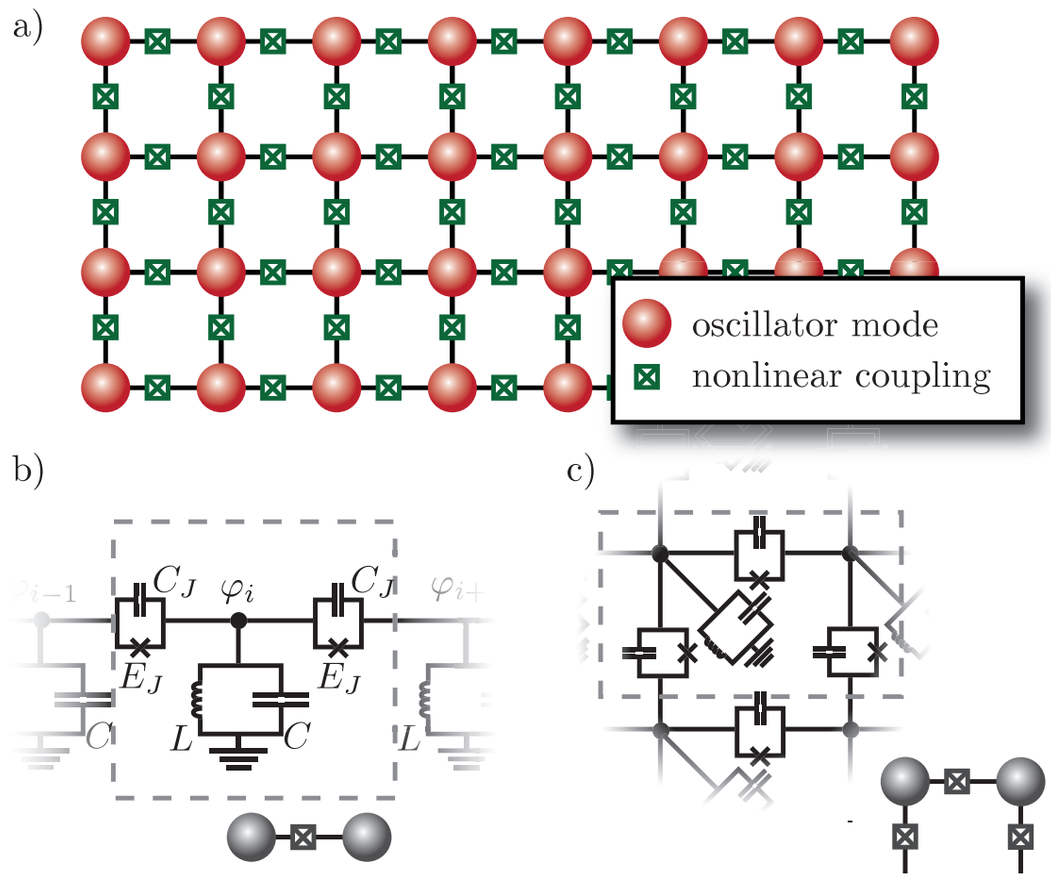
M. J. Hartmann, F.G. Brandao, and M. B. Plenio, Nat. Phys. 2, 849 (2006)
A.D. Greentree et al, Nat. Phys. 2, 856 (2006)
D.G. Angelakis, M.F. Santos, and S. Bose, Phys. Rev. A (RC) 76, 031805 (2007)

Coupled cavity arrays

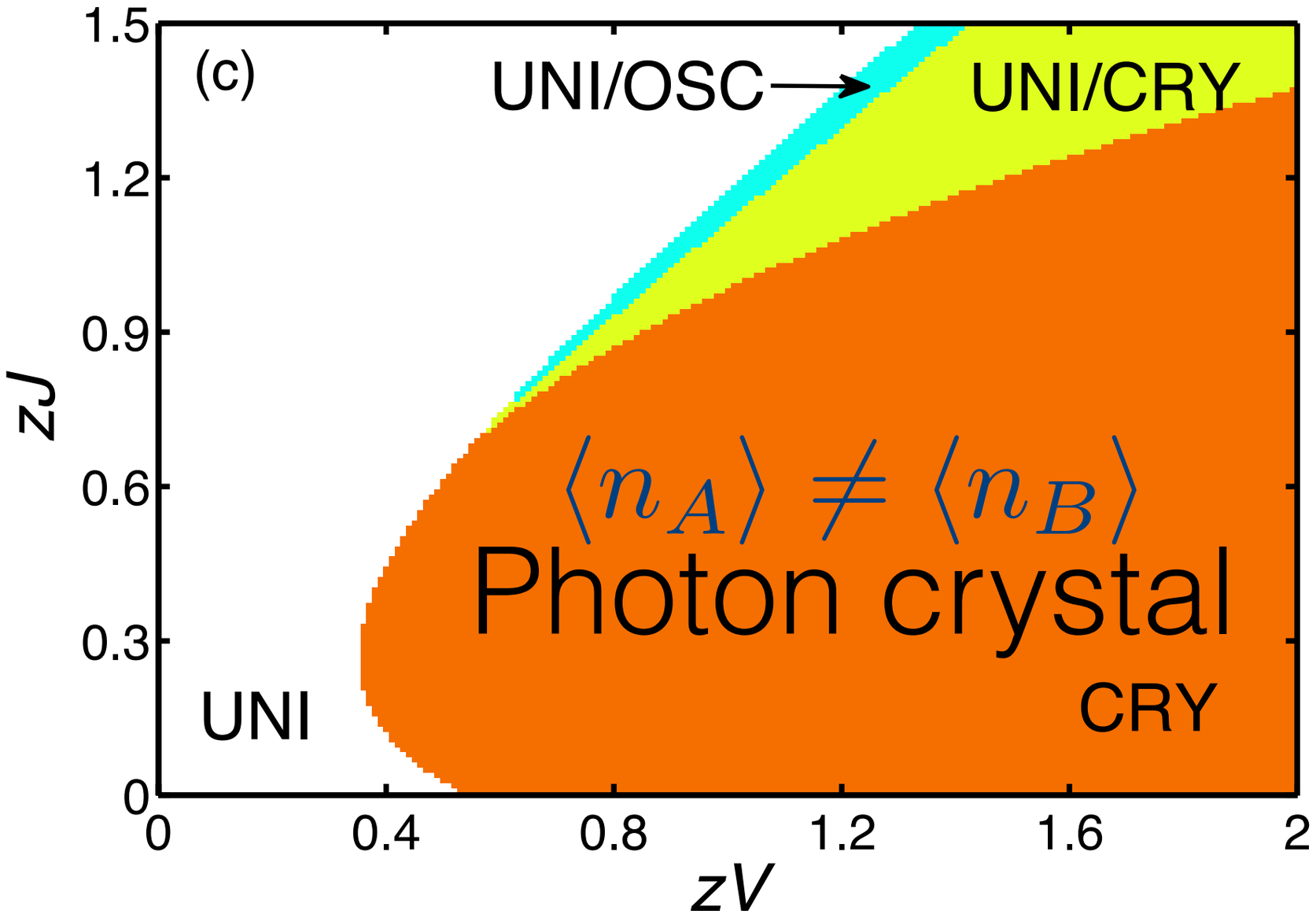


Ultra-strong coupling (Rabi-Hubbard model)

Ideal platform to study dissipative transitions

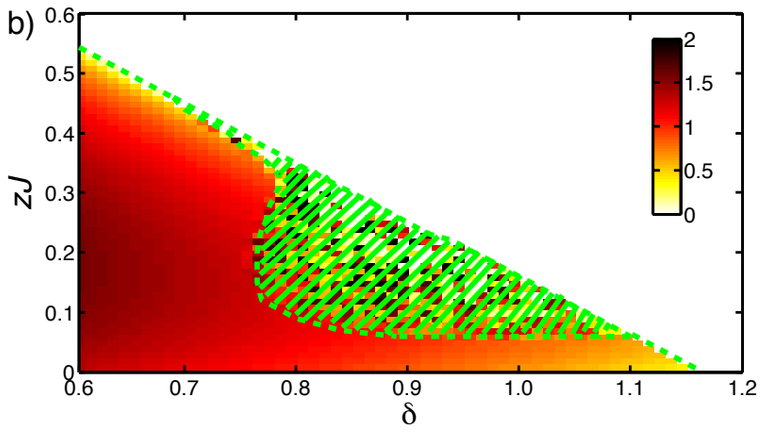


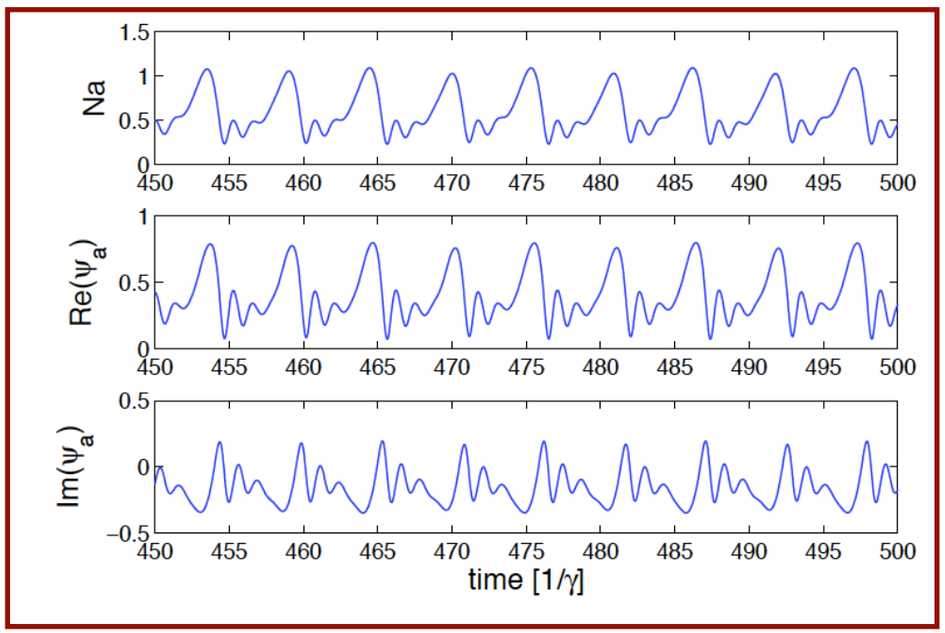
Steady state phase diagram

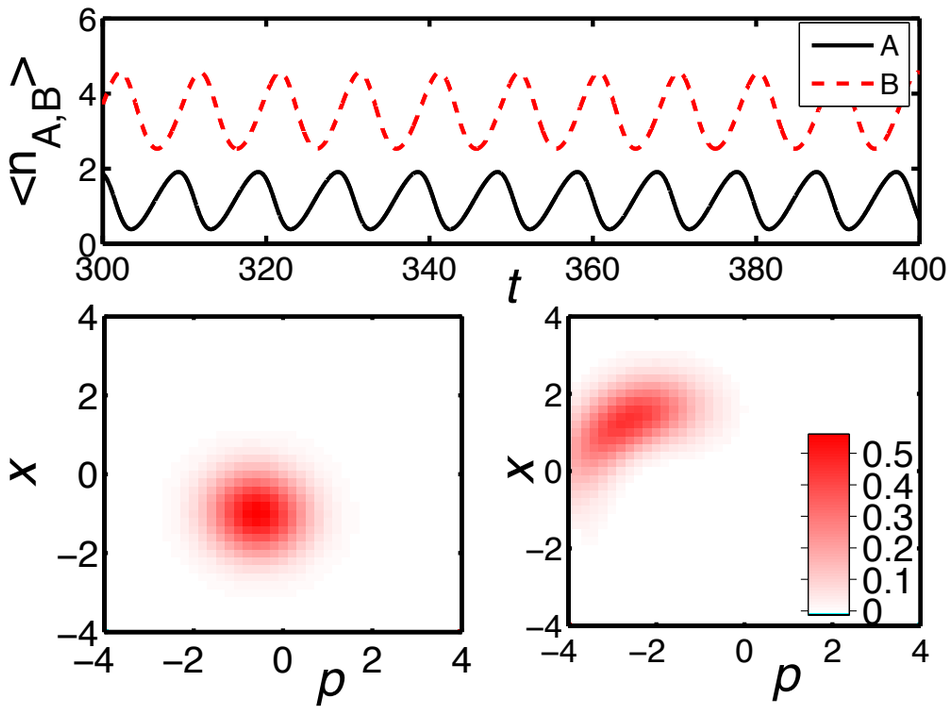


Steady state phase diagram

Sublattice phase synchronization (superfluidity)





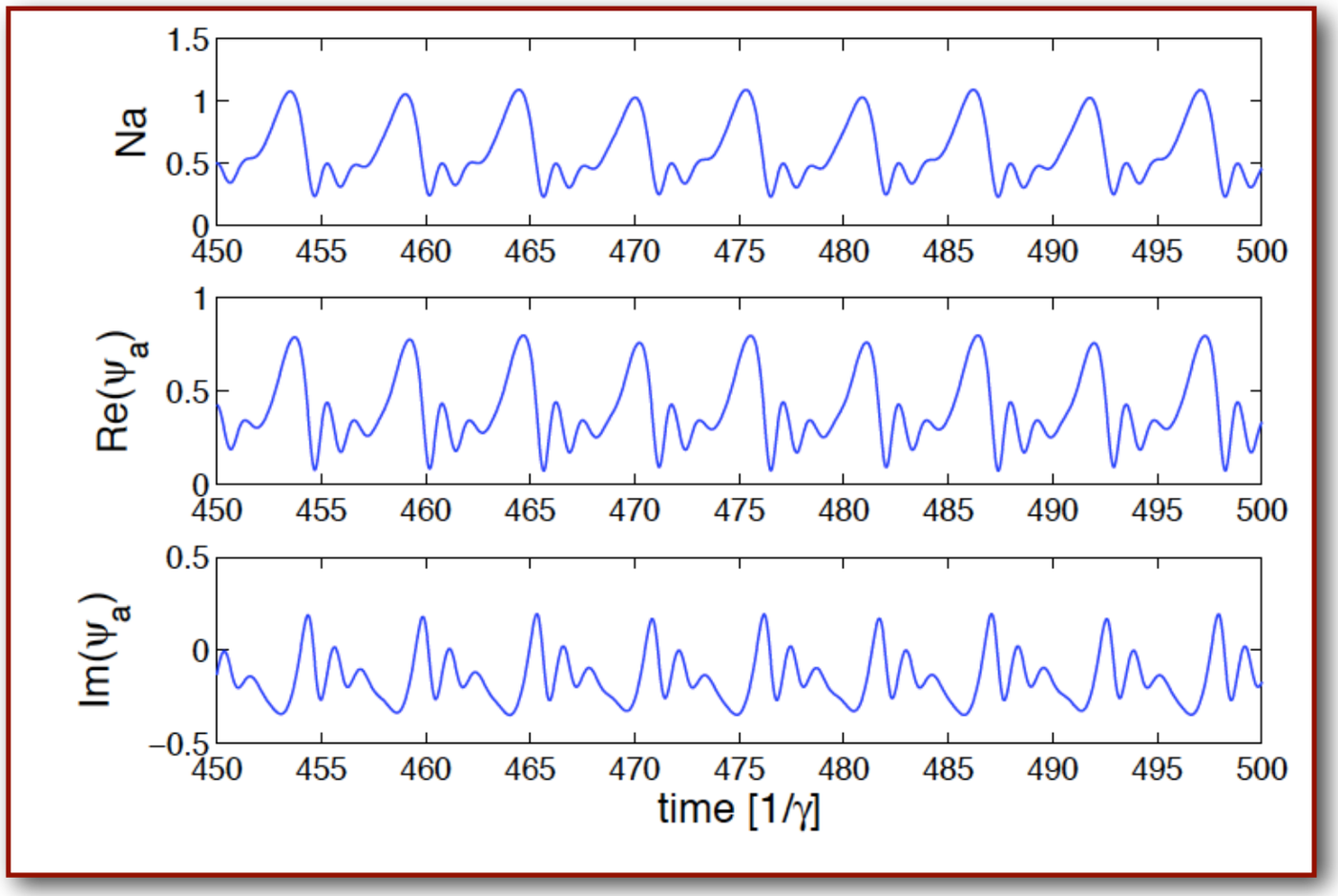


Steady state supersolid ??

Dissipative phase transitions - approach to the steady states

$$\dot{\rho} = -i[\mathcal{H}, \rho] + \mathcal{L}[\rho]$$

Spontaneous breaking of time-translational invariance



"Time-crystals" out of equilibrium

See F. Wilczek for definition of time-crystals

Chan et al arXiv:1501.0979 discuss these limit cycles in the steady state

Conclusions

- Dissipative phase transitions in artificial networks: a very rich arena to investigate critical phenomena out of equilibrium

- A large variety of experimental systems: Cavity arrays, engineered dissipation in optical lattices, BEC in cavities, exiton-polariton condensates, Rydberg atoms, ...